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(54) **STRUCTURE AND METHOD FOR LED WITH PHOSPHOR COATING**

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See application file for complete search history.

(71) Applicant: **EPISTAR CORPORATION**, Hsinchu (TW)

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(72) Inventors: **Chi Xiang Tseng**, Kaohsiung (TW);  
**Hsiao-Wen Lee**, Hsinchu (TW);  
**Tien-Ming Lin**, Hsinchu (TW);  
**Min-Sheng Wu**, Guanyin Township (TW)

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(73) Assignee: **EPISTAR CORPORATION**, Hsinchu (TW)

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This patent is subject to a terminal disclaimer.

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*Primary Examiner* — Lex Malsawma

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(74) *Attorney, Agent, or Firm* — Muncy, Geissler, Olds & Lowe, P.C.

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(63) Continuation of application No. 13/308,715, filed on Dec. 1, 2011, now Pat. No. 8,860,056.

(57) **ABSTRACT**

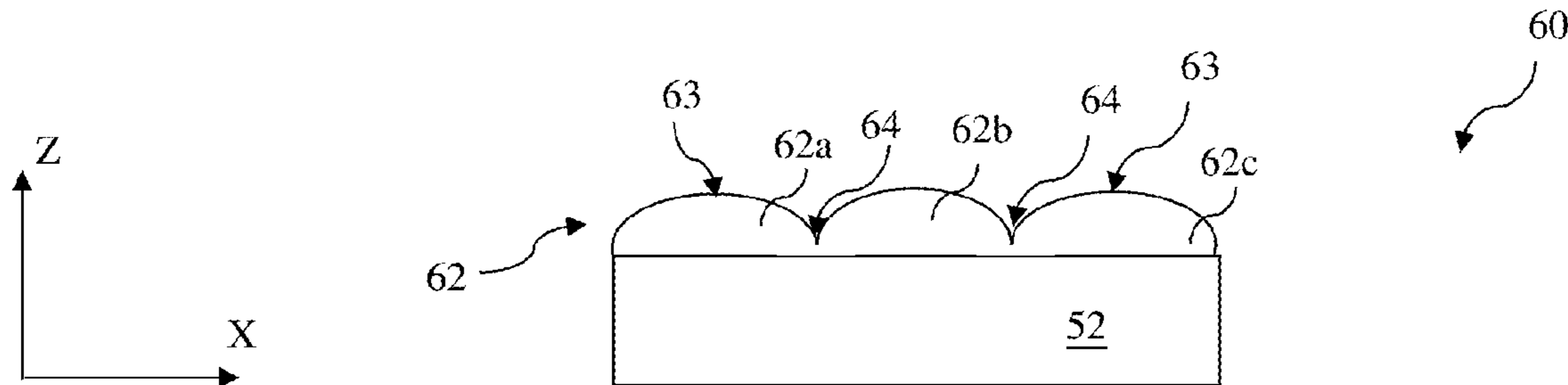
(51) **Int. Cl.**  
**H01L 33/50** (2010.01)  
**H01L 27/15** (2006.01)

The present disclosure provides a light emitting diode (LED) apparatus. The LED apparatus includes an LED emitter having a top surface; and a phosphor feature disposed on the LED emitter. The phosphor feature includes a first phosphor film disposed on the top surface of the LED emitter and having a first dimension defined in a direction parallel to the top surface of the LED emitter; a second phosphor film disposed on the first phosphor film and having a second dimension defined in the direction; and the second dimension is substantially less than the first dimension.

(52) **U.S. Cl.**  
CPC ..... **H01L 33/505** (2013.01); **H01L 27/153** (2013.01); **H01L 33/504** (2013.01); **H01L 33/508** (2013.01); **H01L 2933/0041** (2013.01)

(58) **Field of Classification Search**  
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**12 Claims, 9 Drawing Sheets**



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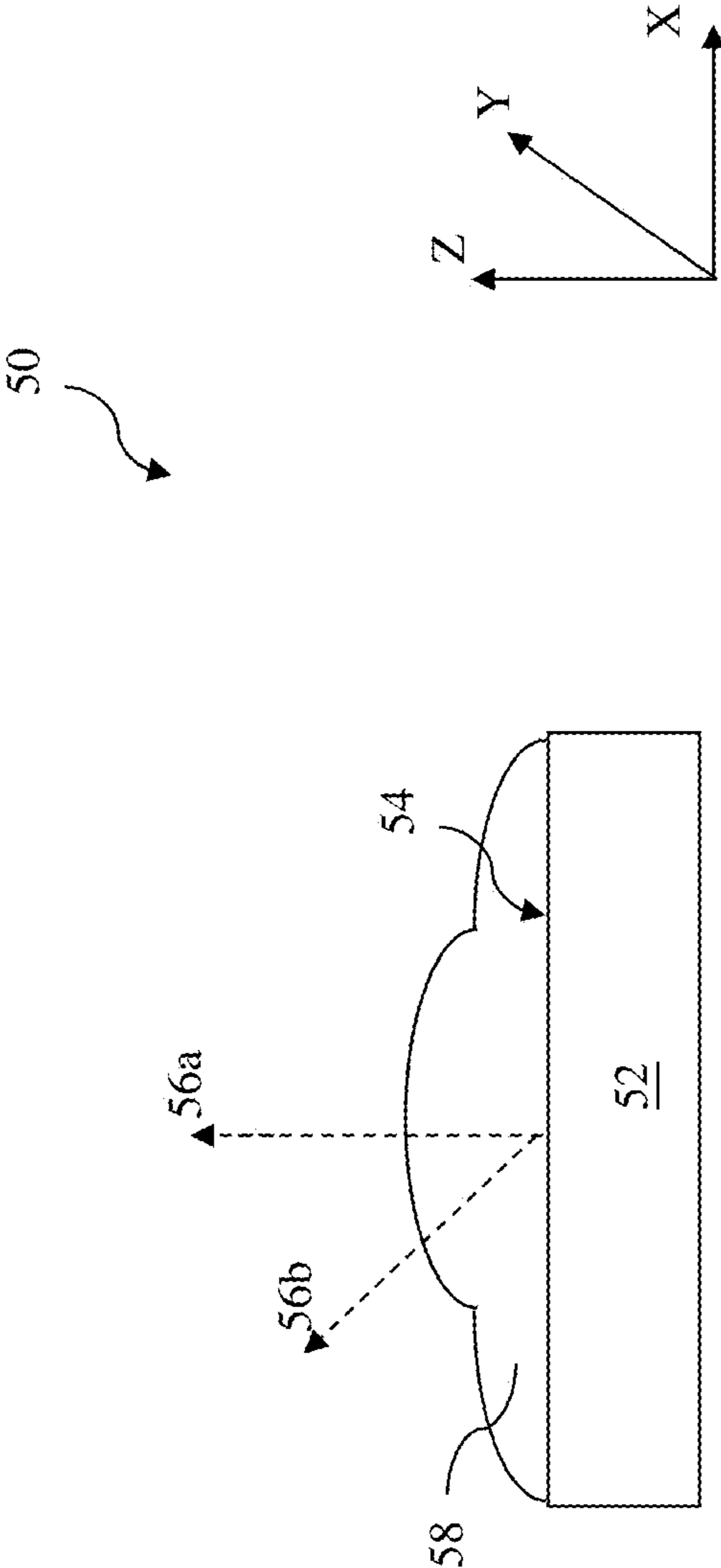
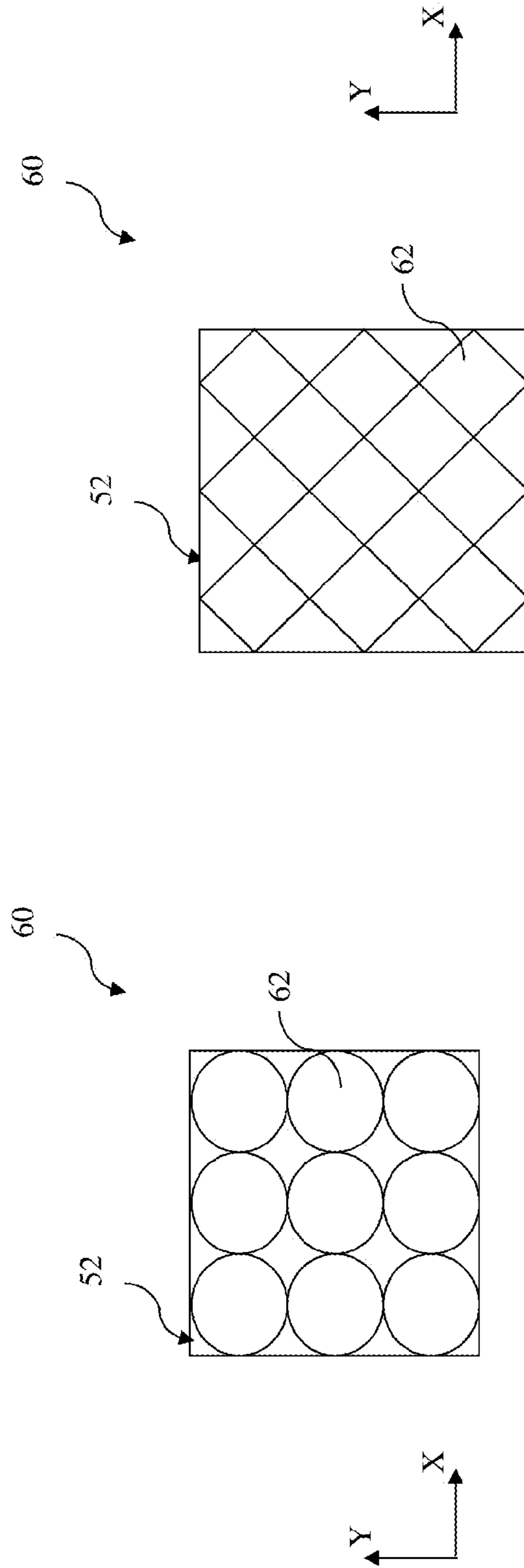
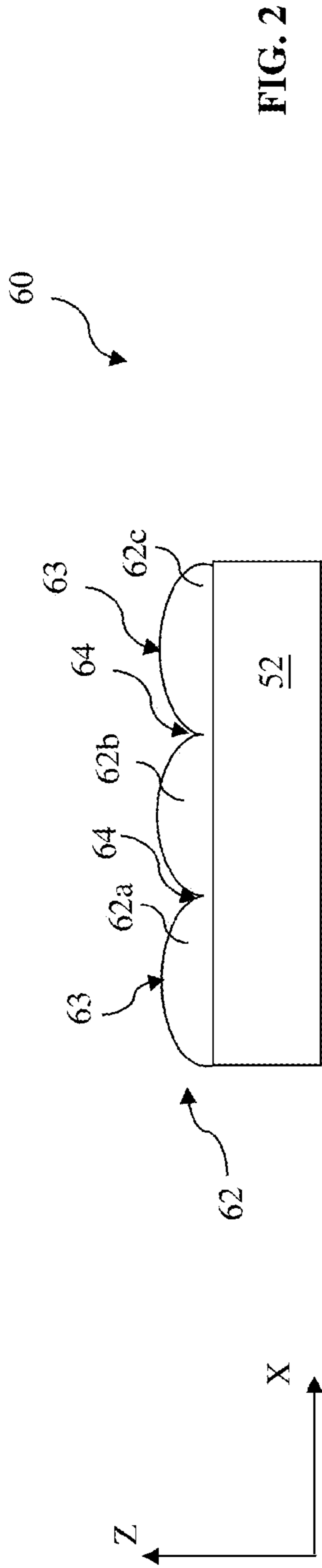


FIG. 1



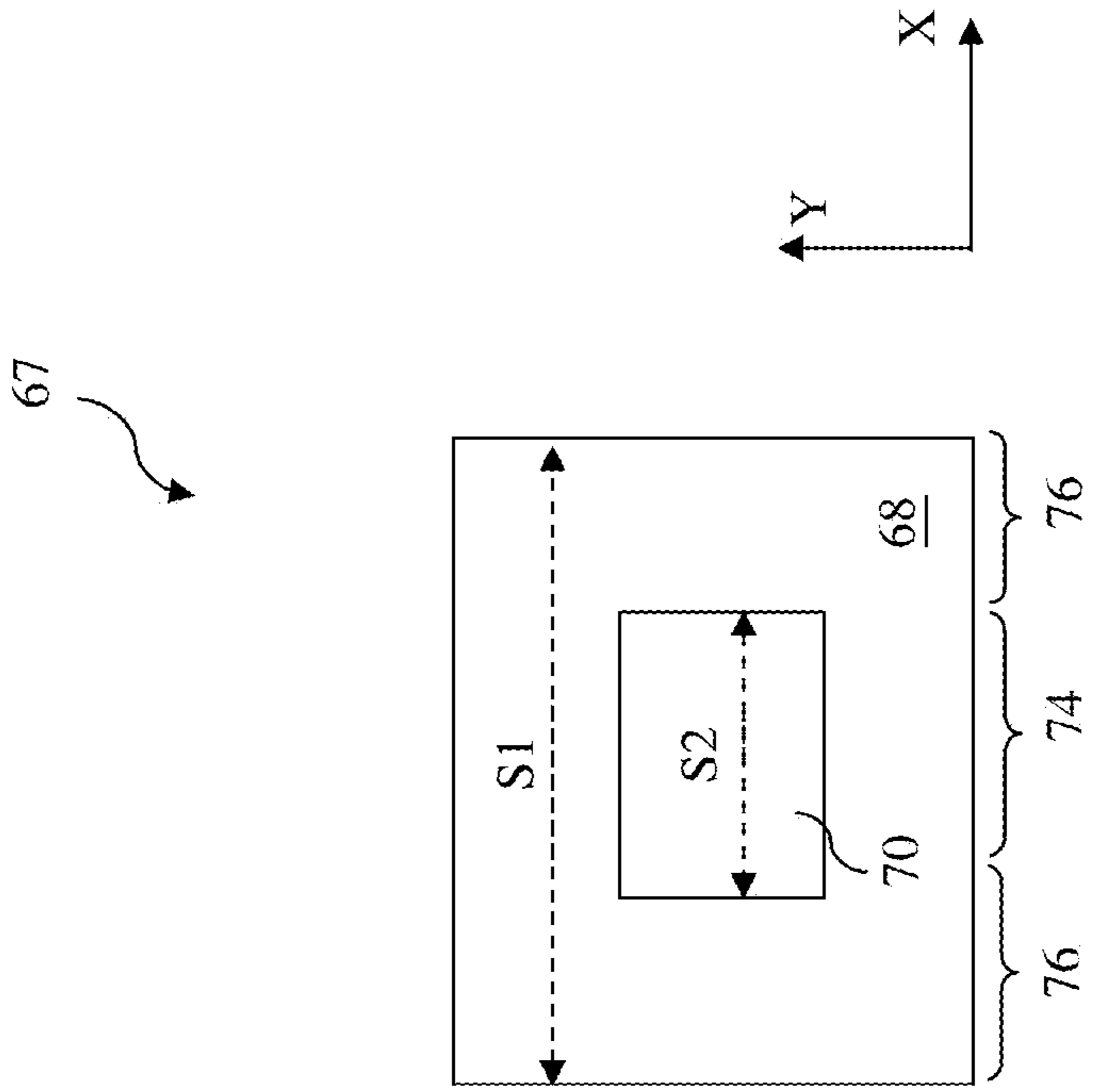


FIG. 4A

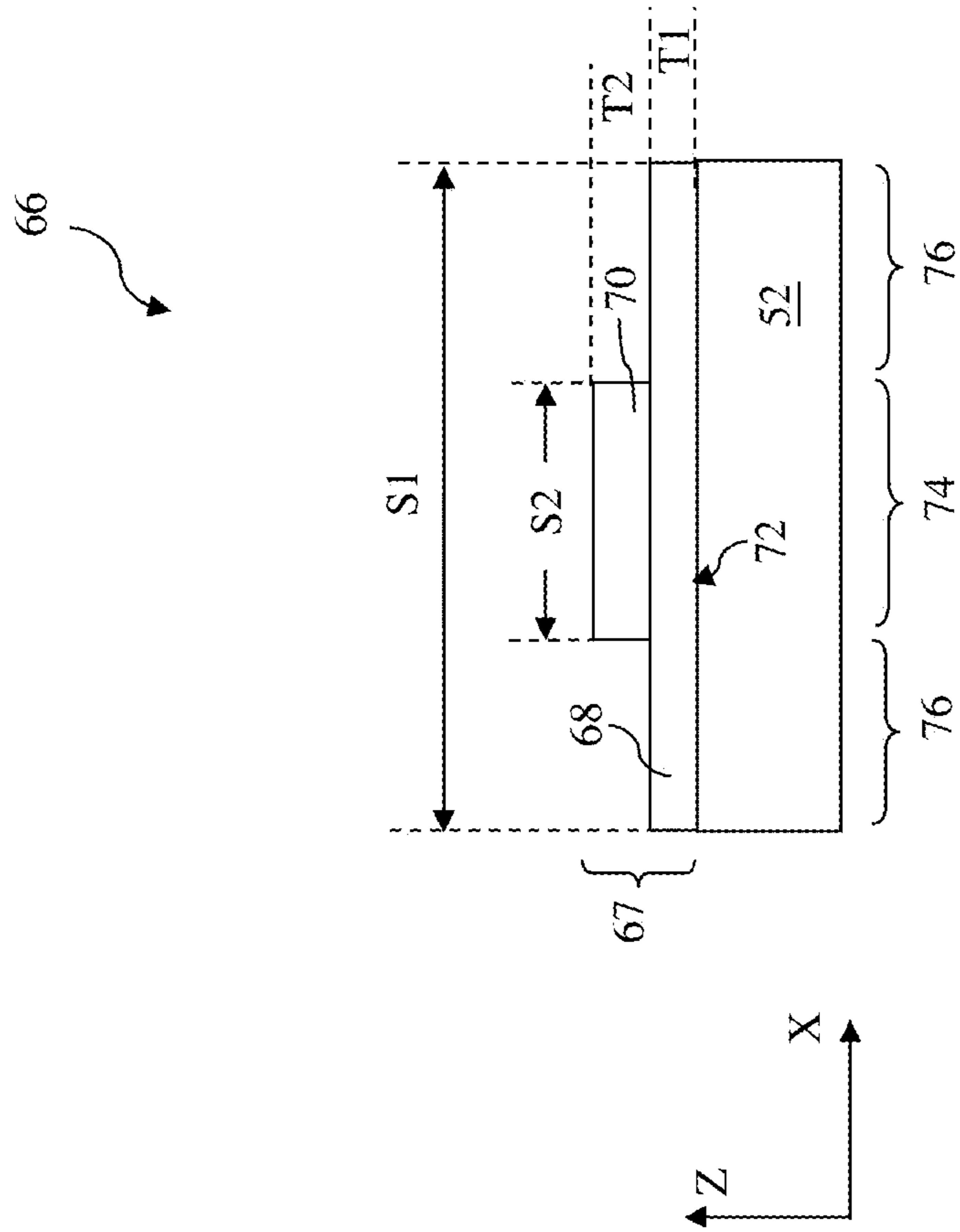
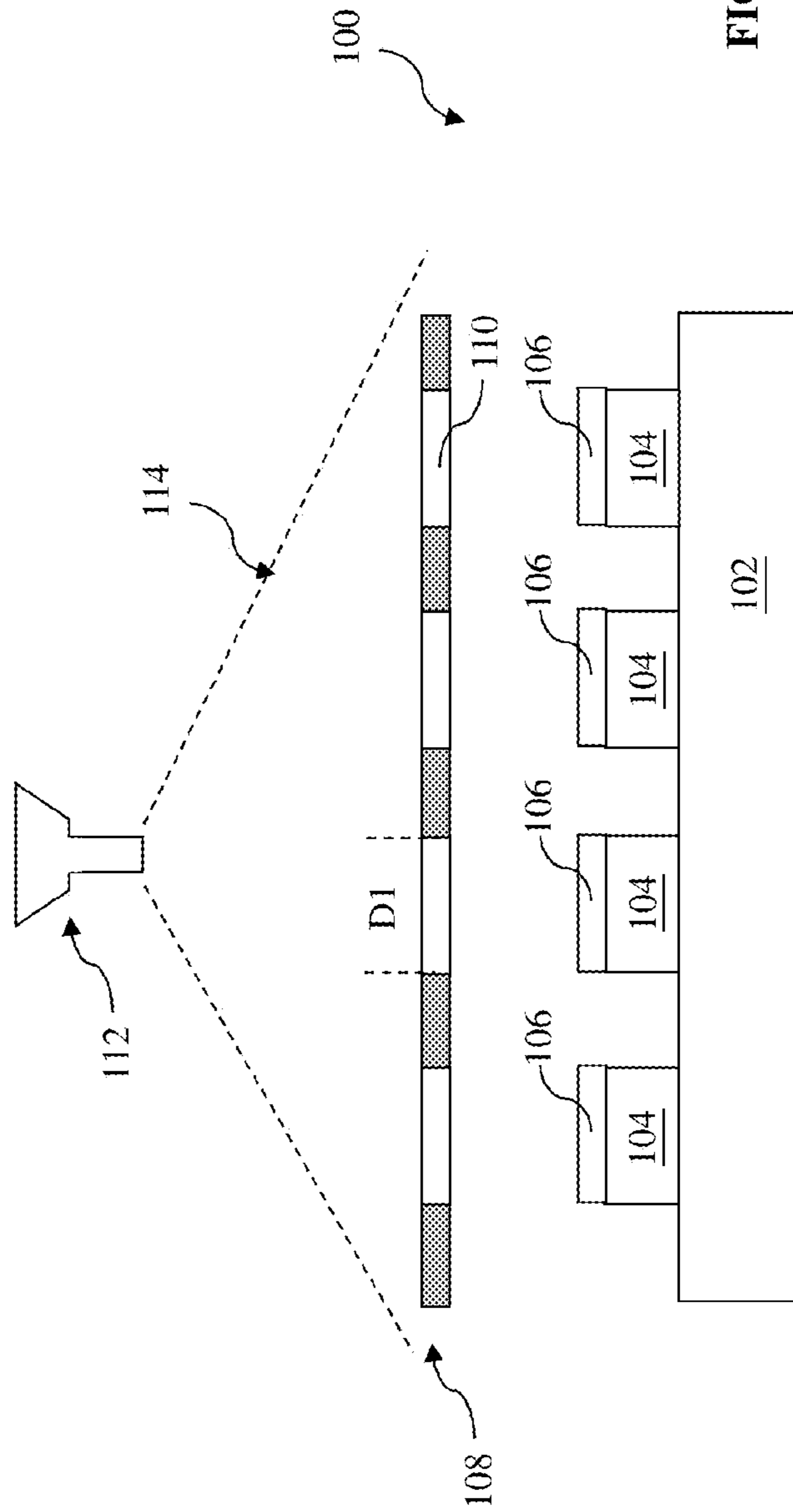
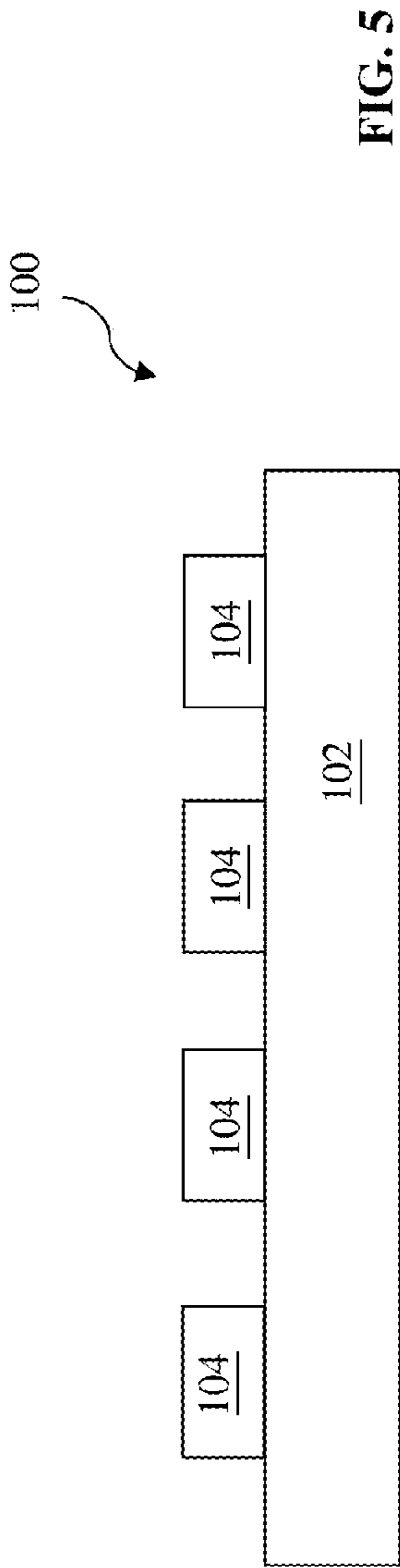


FIG. 4B



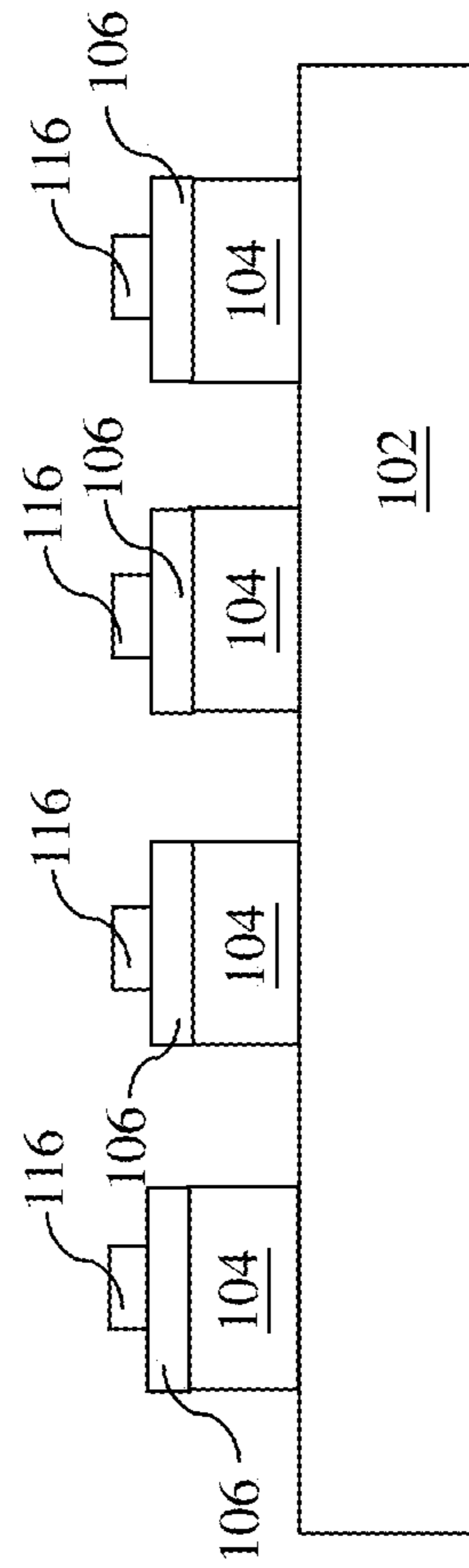
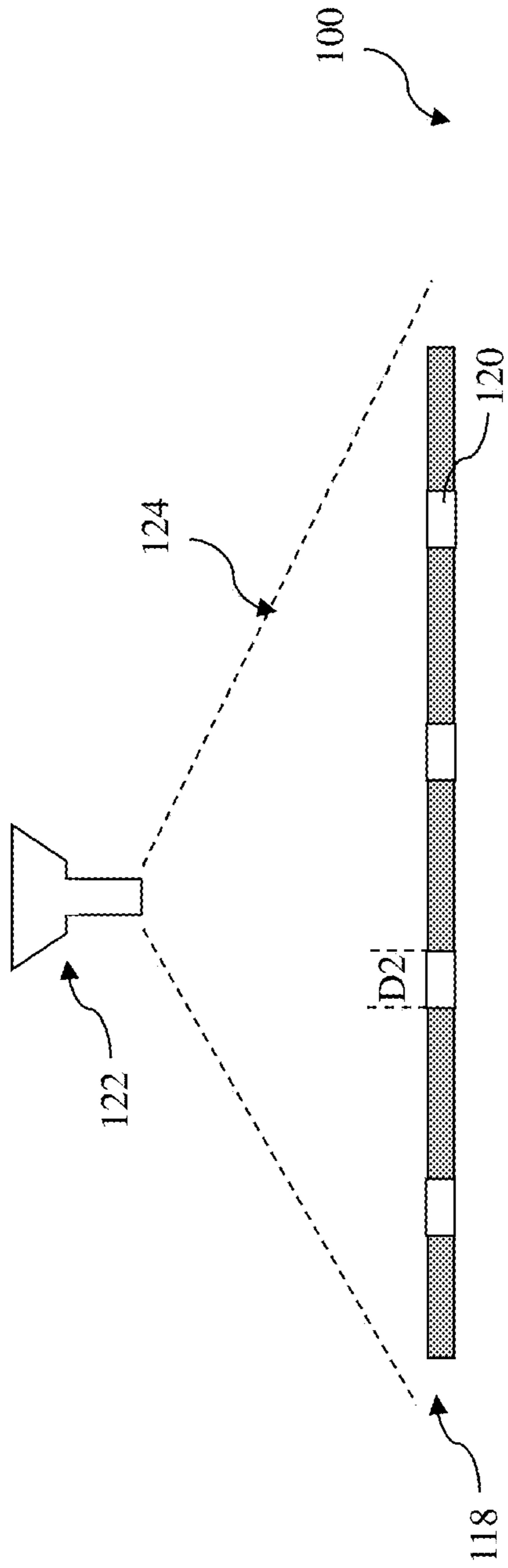


FIG. 7

150

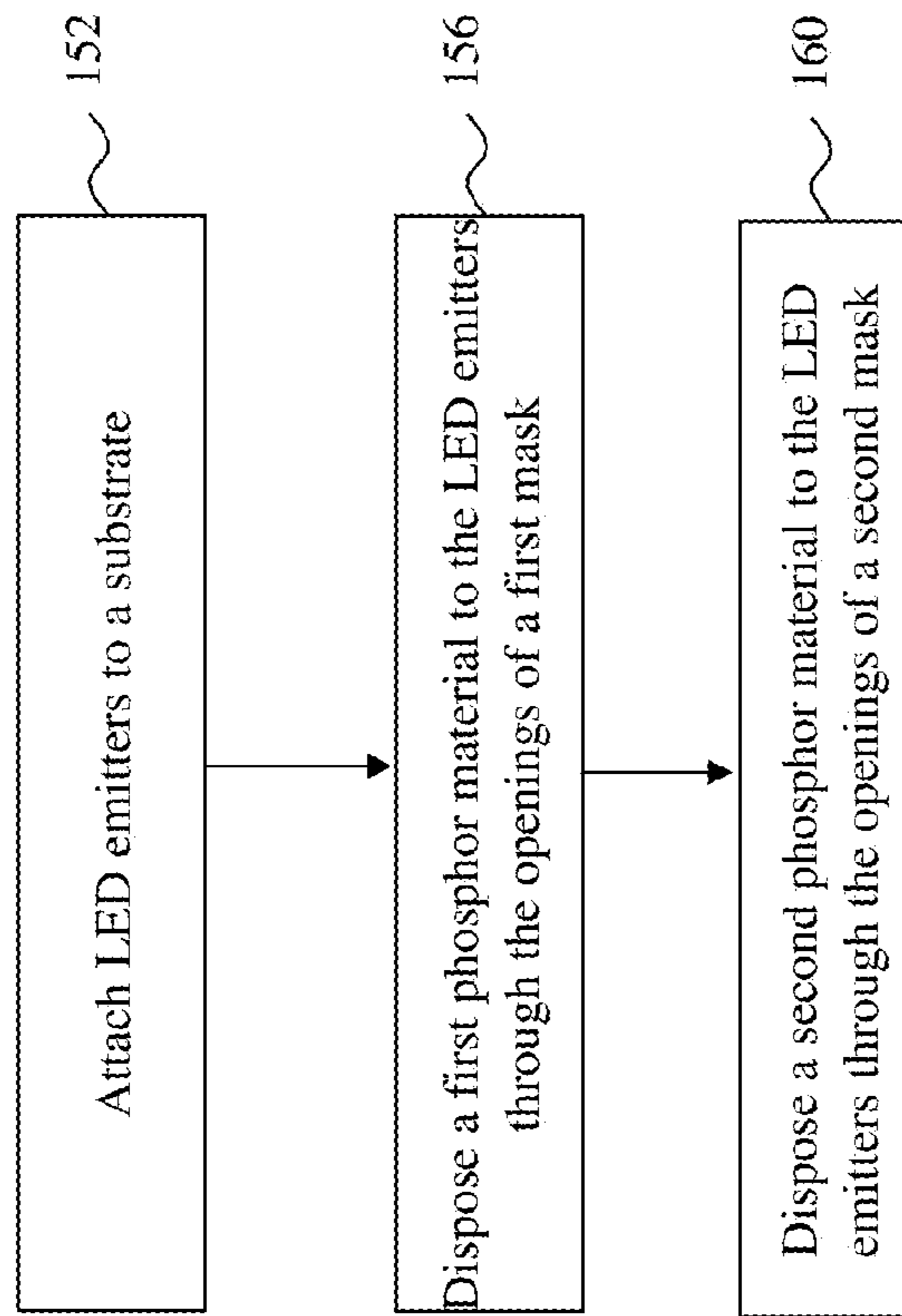


FIG. 8



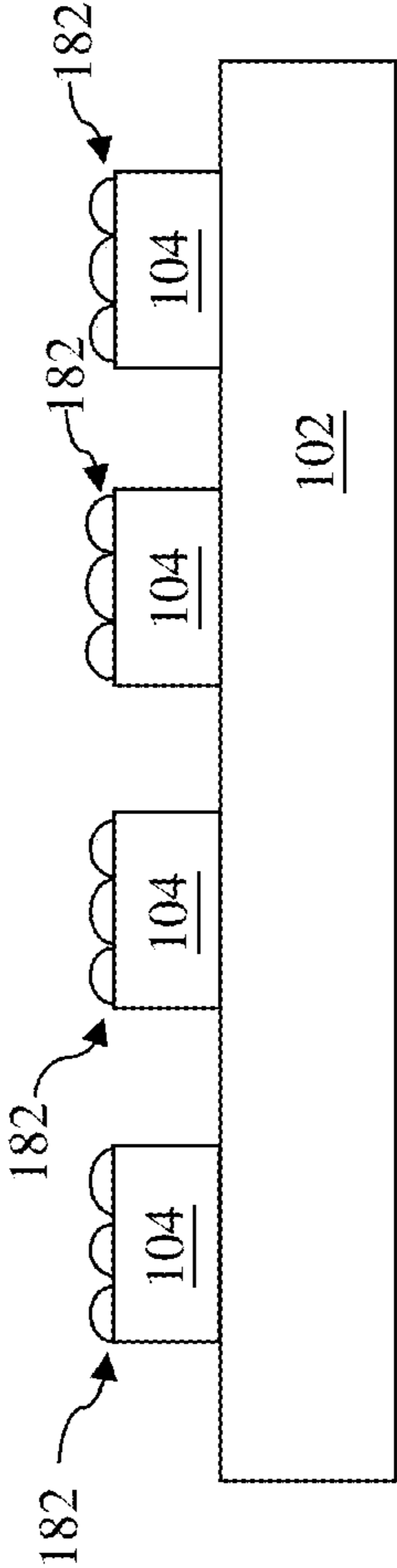
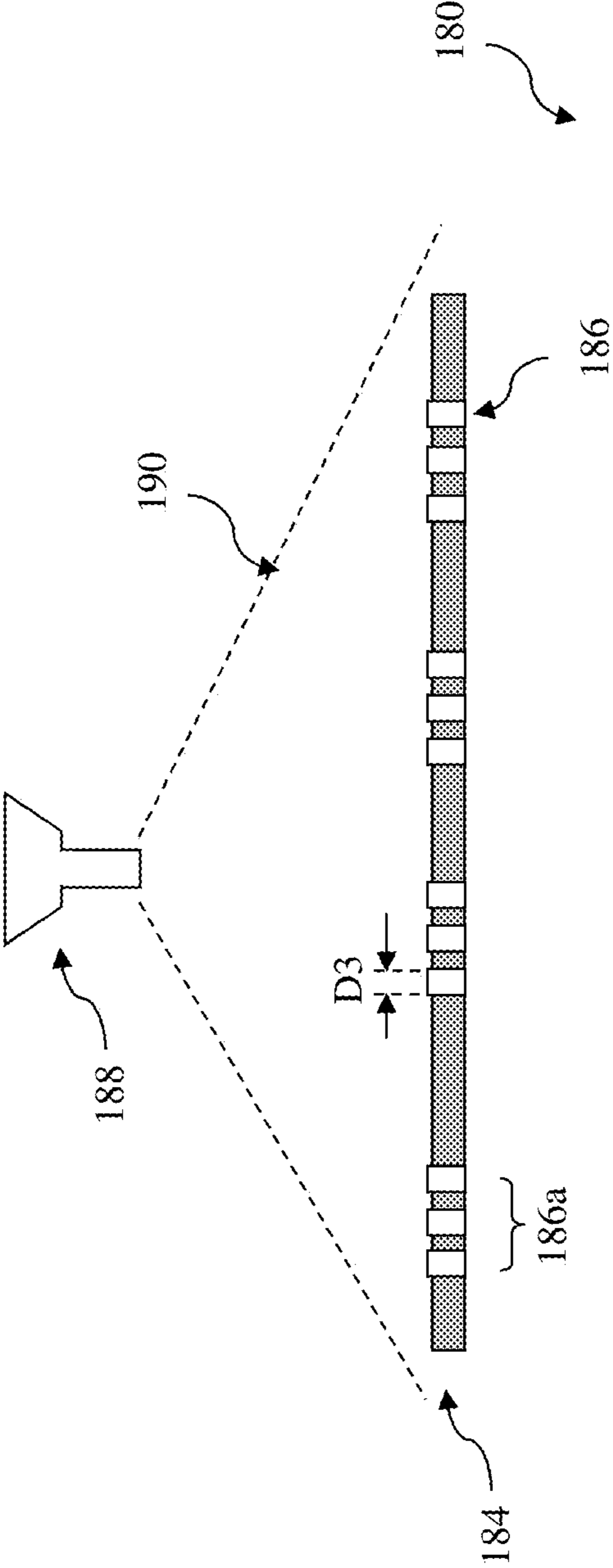


FIG. 9

200

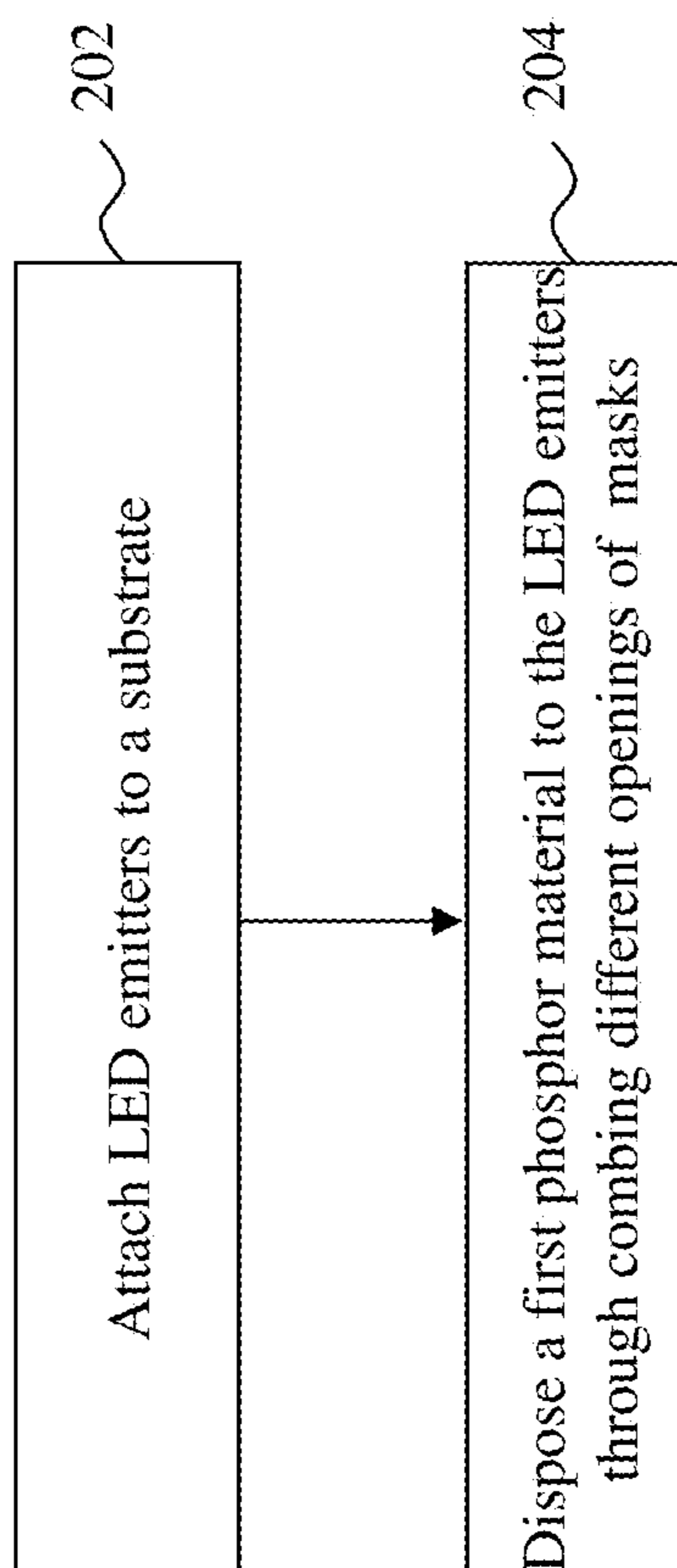


FIG. 10

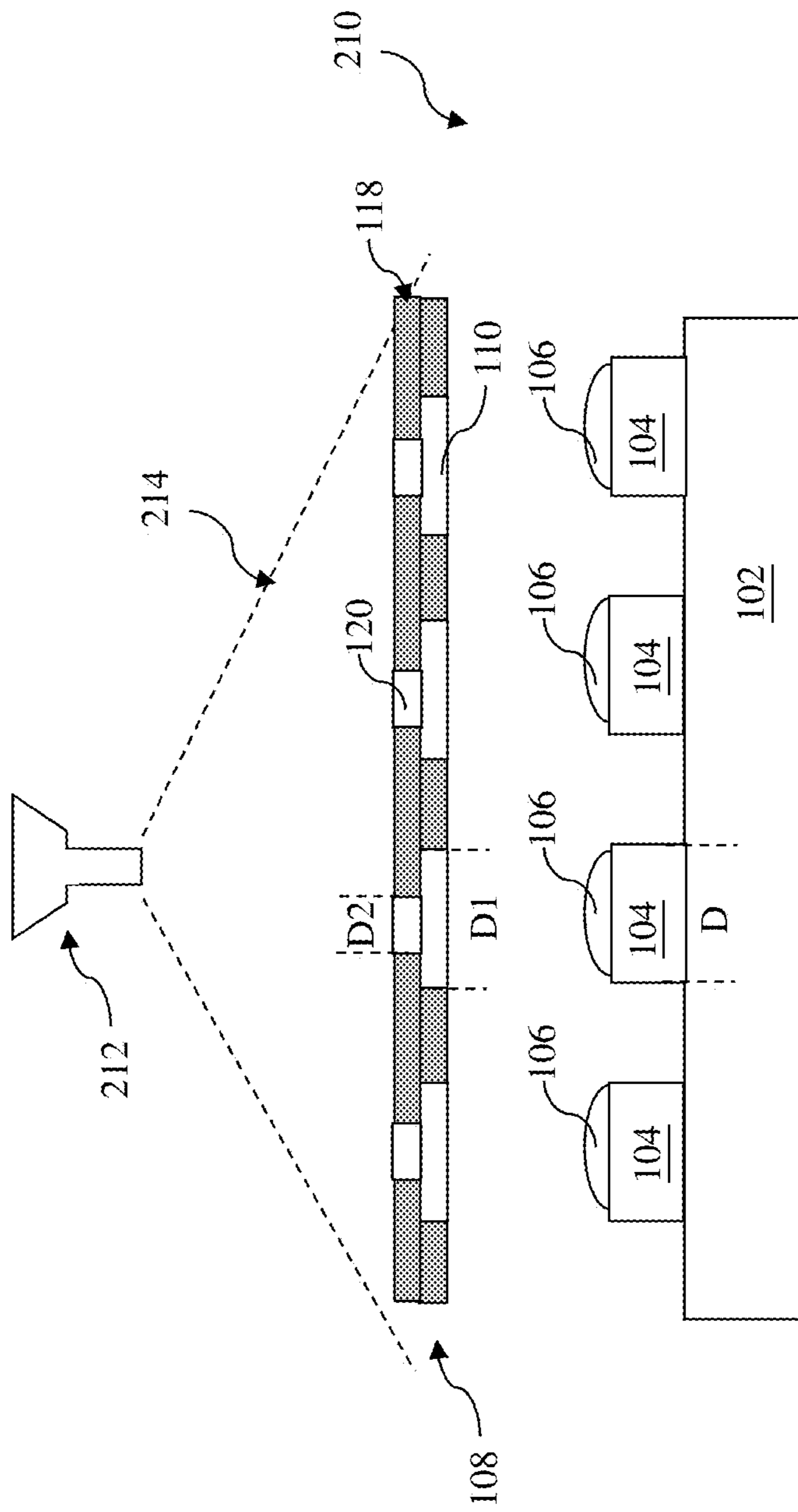


FIG. 11

## 1

STRUCTURE AND METHOD FOR LED WITH  
PHOSPHOR COATING

## PRIORITY DATA

The present application is a continuation application of U.S. patent application Ser. No. 13/308,715, filed on Dec. 1, 2011, entitled "Structure and Method for LED with Phosphor Coating," the disclosure of which is hereby incorporated by reference in its entirety.

## CROSS-REFERENCE

The present disclosure is related to the following commonly-assigned U.S. patent application, the entire disclosure of which is incorporated herein by reference: U.S. Ser. No. 13/150,449 filed Jun. 1, 2011 by inventors Fu-Wen Liu et al for "LED PHOSPHOR PATTERNING".

## BACKGROUND

A light emitting diode (LED) is a semiconductor material impregnated, or doped, with impurities. These impurities add "electrons" and "holes" to the semiconductor, which can move in the material relatively freely. Depending on the kind of impurity, dopants in a doped region of the semiconductor can have predominantly electrons or holes, and is referred to either as an n-type or p-type semiconductor region, respectively. In LED applications, the semiconductor includes an n-type semiconductor region and a p-type semiconductor region. A reverse electric field is created at the junction between the two regions, which cause the electrons and holes to move away from the junction to form an active region. When a forward voltage sufficient to overcome the reverse electric field is applied across the p-n junction, electrons and holes are forced into the active region and combine. When electrons combine with holes, they fall to lower energy levels and release energy in the form of light.

During operation, a forward voltage is applied across the p-n junction through a pair of electrodes. The electrodes are formed on the semiconductor material with a p-electrode formed on the p-type semiconductor region and an n-electrode formed on the n-type semiconductor region.

LED lighting typically uses phosphor materials to generate different color(s) from the LED and enhance color rendering index (CRI). An LED emits light with angle dependent intensity distribution. When a phosphor material is applied to an LED, it converts a portion of the light into a different color that is mixed with the unconverted portion. Depending on the angle, more or less light is converted, resulting in different colors after mixing. As perceived, the color, color temperature, and intensity of resulting light have an angle distribution. Additionally, due to multiple reflection at various interfaces, the light extraction efficiency is reduced.

Accordingly, what is needed is structure of an LED devices with phosphor coating and a method of making the same to address the above issues.

## BRIEF DESCRIPTION OF THE DRAWINGS

Aspects of the present disclosure are best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

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FIG. 1 illustrates an LED apparatus with a phosphor coating in accordance with various embodiments of the present disclosure.

FIG. 2 is a sectional view of an LED apparatus with a phosphor coating in accordance with one embodiment of the present disclosure.

FIG. 3A is a top view of the LED apparatus of FIG. 2 in accordance with one embodiment of the present disclosure.

FIG. 3B is a top view of the LED apparatus of FIG. 2 in accordance with another embodiment of the present disclosure.

FIG. 4A is a sectional view of an LED apparatus with a phosphor coating in accordance with various embodiments of the present disclosure.

FIG. 4B is a top view of the LED apparatus of FIG. 4A in accordance with one embodiment of the present disclosure.

FIGS. 5 through 7 are sectional views of an LED apparatus with a phosphor coating at various fabrication stages in accordance with various embodiments of the present disclosure.

FIG. 8 is a flowchart illustrating a method of fabricating an LED apparatus in accordance with various aspects of the present disclosure.

FIG. 9 is a sectional view of an LED apparatus with a phosphor coating at a fabrication stage in accordance with various embodiments of the present disclosure.

FIG. 10 is a flowchart illustrating a method of fabricating an LED apparatus in accordance with various aspects of the present disclosure in another embodiment.

FIG. 11 is a sectional view of an LED apparatus with a phosphor coating at a fabrication stage in accordance with another embodiment of the present disclosure.

## DETAILED DESCRIPTION

It is understood that the following disclosure provides many different embodiments, or examples, for implementing different features of the disclosure. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. Various features may be arbitrarily drawn in different scales for the sake of simplicity and clarity. It is noted that the same or similar features may be similarly numbered herein for the sake of simplicity and clarity. In addition, some of the drawings may be simplified for clarity. Thus, the drawings may not depict all of the components of a given apparatus (e.g., device) or method.

FIG. 1 illustrates a light emitting apparatus (or light emitting device) 50 with a phosphor coating in accordance with various embodiments of the present disclosure. With reference to FIG. 1, the light emitting apparatus 50 and the method of making the same are collectively described.

The light emitting apparatus 50 includes a light-emitting device 52, such as a light emitting diode (LED or LED emitter). Accordingly, the light emitting apparatus 50 is also referred to as LED apparatus. The light emitting apparatus 50 includes a semiconductor p-n junction that can emit spontaneous radiation in ultraviolet, visible, or infrared regions of the electromagnetic spectrum. In one embodiment, the LED emits blue light, such as a blue light having an emission peak ranging from about 430 nm to about 490 nm. The LED is formed on a substrate, such as a sapphire, silicon carbide, gallium nitride (GaN), or silicon substrate.

In one embodiment, the LED includes an n-type impurity doped cladding layer and a p-type doped cladding layer formed on the n-type doped cladding layer. In one example, the n-type cladding layer includes n-type gallium nitride

(n-GaN), and the p-type cladding layer includes p-type gallium nitride (p-GaN). Alternatively, the cladding layers may include GaAsP, GaPN, AlInGaAs, GaAsPN, or AlGaAs doped with respective types. The LED may further include an indium gallium nitride/gallium nitride (InGaN/GaN) multi-quantum well layer disposed between the n-GaN cladding layer and the p-GaN cladding layer. The LED may further include a buffer layer, such as a GaN buffer layer, formed between the substrate and the n-GaN cladding layer. The LED may further include an InGaN/GaN layer formed on the p-GaN cladding layer. A transparent conductive layer, such as indium tin oxide (ITO), may be formed on the p-GaN cladding layer, coupled to a p-electrode. An n-electrode is formed on and coupled with the n-GaN cladding layer.

The light emitting device **52** includes a top surface **54** defined by two perpendicular axes (or directions): X axis and Y axis. A third direction perpendicular to the top surface or perpendicular to both X and Y axes is referred to as Z axis (or Z direction). When a proper electrical bias is applied to the two electrodes of the light emitting device **52**, the light emitting device **52** will emit light. In one example, the light emitting device **52** emits a light beam **56a** toward a forward direction (Z direction) perpendicular to the top surface **54**, referred to as  $CCD(0^\circ)$ . In another example, the light emitting device **52** emits a light beam **56b** toward a direction having an angle with the forward direction of about  $45^\circ$ , referred to as  $CCD(45^\circ)$ .

The LED is provided for only illustration and may vary in various applications. Further, the light emitting device **52** is not limited to the LED. Other types of light emitting devices may be additionally or alternatively formed or used. The light emitting device **52** may include other features such as a drive circuit integrated in an integrated circuit chip.

The light emitting apparatus **50** further includes a phosphor feature **58** attached on the light emitting device **52**. The phosphor feature **58** includes a luminescent material (or phosphor or phosphor material) that emits light under light excitation. The phosphor is used to change the spectrum of the emitted light for proper illumination effect, such as white illumination. Particularly, the phosphor material is excited by the light of the light emitting device **52** and emits a light of a wavelength greater than that of the light from the light emitting device **52**. In one embodiment, the phosphor material emits visual light, such as yellow light and/or red light upon blue or ultraviolet (UV) excitation. In one embodiment, the phosphor material includes a nitridosilicate phosphor doped by a rare earth element. In another embodiment, the phosphor material includes two or more types of phosphors each being designed to emit light with a respective spectrum (or peak wavelength).

Accordingly, the light emitted from the light emitting apparatus **50** includes a first portion directly from the light emitting device **52** and a second portion emitted from the phosphor material(s) in the phosphor feature **58**.

Phosphor material itself is usually in powder and needs a carrying material when being applied to the light emitting device **52**. In one embodiment, the phosphor feature **58** is a composite material having a phosphor powder dispersed in a carrying material that is transparent to the light from the light emitting apparatus **50**. Particularly, the phosphor feature **58** includes a phosphor gel. The phosphor gel includes a gel or gel-like material with phosphor powder dispersed in. In one example, the phosphor gel includes silicone or epoxy with phosphor powder dispersed in. After the phosphor gel is applied to the light emitting device, it may be cured to a solid state at a high temperature.

In one embodiment, the phosphor feature **58** is disposed on the light emitting device **52** using a suitable technique, such as

spraying. Other suitable technique may be utilized to form the phosphor feature **58** on the light emitting device **52** with a desired pattern (or a surface profile). In one embodiment, a mask having a plurality of openings is used for forming the phosphor feature **58**. The phosphor gel may be sprayed to the light emitting device **52** through the openings of the mask. The mask includes a mask substrate of a material, such as metal, quartz or ceramic material, with the openings formed in the mask substrate. The corresponding mask and the method to form the phosphor feature **58** are further described later.

The phosphor feature **58** is disposed and patterned to have a non-uniform structure and/or a non-flat surface profile such that the emitted light from the light emitting apparatus **50** has a less dependence over the emitting angle, enhancing the emitting light quality and reducing the relative change of the correlated color temperature (CCT) of the emitted light from the light emitting apparatus **50**. The relative change of the CCT is defined as the difference between the CCT at different emitting angle, such as a difference between the CCT at the forward direction  $CCD(0^\circ)$  and the CCT at the direction perpendicular to the forward direction  $CCD(90^\circ)$ .

FIG. 2 illustrates a sectional view of one embodiment of a light emitting apparatus **60** having a light emitting device **52** and a phosphor feature **62** disposed on the light emitting device **52**. The phosphor feature **62** is patterned to have a plurality of sub-features, such as **62a**, **62b** and **62c** illustrated in FIG. 2. The sub-features of the phosphor feature **62** are configured in an array. In one example, the sub-features of the phosphor feature **62** are configured in a periodic array.

FIG. 3A illustrates a top view of the light emitting apparatus **60** constructed according to aspects of the present disclosure in one embodiment. The sub-features of the phosphor feature **62** are in disk shape in the top view. Alternatively, the sub-features of the phosphor feature **62** may be shaped as squares, polygons, or other geometries, in the top view. Gaps may be formed between the sub-features of the phosphor feature **62**, such as those shown in FIG. 3A.

FIG. 3B illustrates a top view of the light emitting apparatus **60** constructed according to aspects of the present disclosure in another embodiment. The phosphor feature **62** are patterned to a plurality of sub-features with square shape.

Still referring to FIG. 2, the phosphor feature **62** has an uneven surface profile that includes a plurality of peak points **63** and a plurality of dip points **64** interdigitated with each other. The dip points **64** are substantially below the peak points **63** in a sectional view. The surface of the phosphor feature between neighbor peak point and dip point is curved. In the present embodiment, each sub-feature of the phosphor feature **62** is defined between two neighbor dip points **64**.

In the depicted embodiment, the sub-features of the phosphor feature **62** are substantially same in shape and size, and are further configured in a periodic array. Particularly, the dip points **64** are periodically configured along a horizontal direction, such as X axis, as illustrated in FIG. 2. Similarly, the peak points **63** are periodically configured along the same horizontal direction as well.

The light emitting apparatus **60** includes a phosphor feature **62** with an uneven surface profile and presents certain advantages in various embodiments. In one example, the surface profile of the light emitting apparatus **60** reduces the reflection of the emitted light at the surface of the phosphor feature **62**. When the light reflection is strong, the angle distribution of the emitted light is more frequency (or wavelength) dependent. The correlated color temperature (CCT) is accordingly angle dependent. The relative change of the CCT is higher. By reducing the reflection of the emitted light by the

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disclosed phosphor feature 62, the relative change of the CCT is reduced and the light quality is improved for various applications, such as illumination.

FIG. 4A illustrates a sectional view of a light emitting apparatus 66 constructed according to aspects of the present embodiment in another embodiment. FIG. 4B illustrates a top view of a phosphor feature 67 in the light emitting apparatus 66 constructed according to aspects of the present embodiment.

Referring to FIGS. 4A and 4B, the light emitting apparatus 66 includes a light emitting device 52 and further a phosphor feature 67 disposed on the light emitting device 52. The phosphor feature 67 further includes a first phosphor film 68 disposed on the light emitting device 52 and a second phosphor film 70 disposed on the first phosphor film.

The first phosphor film 68 includes a first phosphor material and the second phosphor film 70 includes a second phosphor material. In one embodiment, the first and second phosphor materials are a same phosphor material, such as a phosphor designed to emit red light under excitation of blue or UV light.

In another embodiment, the first and second phosphor materials are different phosphor materials designed to emit respective lights. For example, the first phosphor material emits a first light having a first peak wavelength. The second phosphor material emits a second light having a second peak wavelength. The second peak wavelength is substantially greater than the first peak wavelength. In another example, the first phosphor material emits yellow light under excitation and the second phosphor material emits red light under the excitation.

Still referring to FIGS. 4A and 4B, the light emitting device 52 has a top surface 72 defined by two perpendicular axes X and Y. A third axis Z is perpendicular to the top surface or the both X and Y axis. The top surface 72 of the light emitting device 52 includes a first region (or central region) 74 and a second region (or surrounding region) 76 surrounding the first region 74. The first phosphor film 68 is disposed on the top surface of the light emitting device 52 in both the first region 74 and the second region 76. The second phosphor film 70 is disposed on the first phosphor film 68 only with the first region 74.

In a sectional view as illustrated in FIG. 4A, the first phosphor film 68 has a first thickness T1 and the second phosphor film 70 has a second thickness T2. the phosphor feature 67 has an uneven surface profile that has a central thickness in the first region 74 and an edge thickness in the second region 76. The central thickness is substantially greater than the edge thickness. Particularly, the central thickness of the phosphor feature 67 equals to the sum of the first thickness T1 and the second thickness T2. The edge thickness of the phosphor feature 67 equals to the first thickness T1.

Furthermore, the first phosphor film 68 spans in a horizontal direction, such as the X axis, with a first dimension "S1". The second phosphor film 70 spans in the same direction with a second dimension "S2". The second dimension S2 is substantially less than the first dimension S1.

In the present embodiment, the first and second phosphor films 68 and 70 are designed in square shapes, in the top view as illustrated in FIG. 4B. Alternatively, the first and second phosphor films 68 and 70 may be designed to other proper shape, such as disks or rectangles.

The first and second phosphor films 68 and 70 can be formed by spray by a procedure including a first step to form the first phosphor film 68 and a second step to form the second phosphor film 70. Each step may use a mask with respective

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openings such that the phosphor material can be disposed through the openings of the mask.

The light emitting apparatus 66 includes a phosphor feature 67 having a first phosphor film and a second phosphor film on the first phosphor film, as described above. The phosphor feature 67 with the disclosed structure presents certain advantages in various embodiments.

As one example for illustration, in the LED emission, the light of higher frequency and shorter wavelength (e.g., blue) is more directional and the corresponding light intensity is more distributed in a smaller range around the forward direction. Comparably, the light of lower frequency and longer wavelength (e.g., red from the phosphor material) is more non-directional and the corresponding light intensity is more distributed in a broader range around the forward direction. Thus, the light from a light emitting apparatus looks more blue in the forward direction and more red in other directions away from the forward direction. The CCT is changing over the angle, referred to as CCT angle effect. The disclosed phosphor feature 67 reduces the relative change of the CCT and renders the uniform color of the light emitting apparatus.

In one embodiment, both the first and second phosphor films are a same type phosphor material, such as a phosphor material to emit red light. As the second phosphor film is only disposed on a central region, the phosphor feature 67 is thicker in the central region and thin in an edge region surrounding the central region. Accordingly, the forward light (e.g., blue light) from the light emitting device 52 experiences more excitation and emission. The corresponding red light from the phosphor feature 67 in the forward direction is enhanced in intensity. The corresponding red light from the phosphor feature 67 in other direction is reduced in intensity. Thus, the CCT angle effect is substantially compensated. Collectively, the light from the light emitting apparatus 66 (including the light emitting device 52 and the phosphor feature 67) is more uniform with improved illumination quality.

In another embodiment, the first phosphor film includes a first phosphor material and the second phosphor film includes a second phosphor material. For example, the first phosphor material emits yellow light, and so also referred to as yellow phosphor. The second phosphor material emits red light, and so also referred to as red phosphor. As the second phosphor film is only disposed on a central region, the phosphor feature 67 emits red light only in the central region (corresponding to a narrow angle) and emits yellow light in both the central and edge regions (corresponding to a broad angle). Accordingly, the forward light (e.g., blue light) from the light emitting device 52 experiences more excitation and emission. Accordingly, the light from the phosphor feature 67 is more red in the forward direction and more yellow in other directions. Thus, the CCT angle effect is substantially compensated. Collectively, the light from the light emitting apparatus 66 (including the light emitting device 52 and the phosphor feature 67) is more uniform with improved illumination quality.

FIGS. 5 through 7 illustrate sectional views of a semiconductor structure 100 at various fabrication stages constructed according to aspects of the present disclosure in one or more embodiments. The semiconductor structure 100 includes a plurality of light emitting apparatus, such as the light emitting apparatus 66 in FIG. 4A. FIG. 8 is a flowchart of a method 150 making the semiconductor structure 100 in one embodiment. With references to FIGS. 5 through 8, the semiconductor structure 100 and the method 150 are collectively described.

Referring to FIGS. 5 and 8, the method 150 begins at step 152 by attaching to a substrate 102 with a plurality of light emitting devices 104. One example of the light emitting

devices **104** is the light emitting device **52**. In the present embodiment, the light emitting devices **104** are LED chips (or LED emitters). In another embodiment, the substrate **102** includes a semiconductor substrate, such as a silicon wafer. Alternatively, the substrate **102** may include other suitable substrate, such as a metal substrate, a quartz substrate, or a ceramic substrate. In another embodiment, the LED chips are bonded to the substrate **102** with a suitable bonding mechanism, such as eutectic bonding or diffusion bonding. In the present embodiment, various fabrication steps are implemented in a wafer level, resulting in a plurality of LED apparatuses.

In another embodiment, the substrate **102** further includes metal trace designed and configured for proper bonding effect. In yet another embodiment, the substrate **102** may further include other features, such as through silicon via (TSV), for electrical wiring. In another embodiment, the substrate may further include various doped regions and other features configured to provide an integrated circuit, such as a driving circuit, to the LED emitters **104**.

Referring to FIGS. **6** and **8**, the method **150** proceeds to step **156** by dispensing a first phosphor material to the LED emitters **104**, forming a first phosphor film **106** on the LED emitters **104**. In the present embodiment, the first phosphor film **106** is formed by spray using a first mask **108**.

The first mask **108** includes a suitable mask substrate, such as a metal substrate, a ceramic substrate, or a quartz substrate. The first mask **108** also includes various openings (or apertures) **110** formed in the mask substrate. The mask **108** are positioned over the substrate **102** such that the apertures **110** of the mask **108** are aligned with respective LED emitters **104**. The dimensions of mask **108** (aperture widths, aperture locations, and the like) are designed and tuned to define the first phosphor film **106** and the geometry and/or shape of the first phosphor film. In one example, the mask **108** is positioned a distance above the substrate **102** without direct contact with the LED emitters **104**.

The plurality of openings **110** of the first mask **108** may be designed to have a proper shape and size such that the first phosphor film **106** substantially covers the top surface of the LED emitters **104**. In one example, the LED emitters **104** are sawed to square chips. Accordingly, the openings **110** are designed to be square openings as well. Each of the opening **110** in the first mask **108** includes a dimension **D1** as illustrated in FIG. **6**. When the openings **110** are square openings, the dimension **D1** is the width of the respective square opening. In the present embodiment, the LED emitters **104** are sized same. Accordingly, the openings **110** are designed to the same dimension **D1**.

The first phosphor material is applied to the LED emitters **104** through the openings **110** of the first mask **108** by spray. A spray mechanism, such as a spray module (or a spray head) **112**, is provided for spray coating the LED emitters **104**. The spray module **112** is coupled with a supply module to provide the first phosphor material for spray coating **114**.

Furthermore, the dimension of the first phosphor film **106** is related to the dimension **D1** of the openings **110** in the first mask **108**. When the first mask **108** is positioned substantially close to the LED emitters **104** and the first phosphor material is applied to the LED emitters **104** through the openings by spray coating, the dimension of the first phosphor film **106** substantially equals to the dimension **D1** of the openings **110** in the first mask **108**. Advantageously, the first mask **108** is reusable for subsequent production, allowing for reduced costs. For example, after step **156**, the first mask **108** may be cleaned for reuse.

In the present embodiment, the first phosphor material is a composite material having a phosphor powder dispersed in a carrying material, such as silicone or epoxy. In one example, the composite phosphor material is a gel-like material that is able to be sprayed to the coating surface. After the first phosphor material is applied to the LED emitters **104**, a high temperature process may be further applied to cure the coated first phosphor material, forming the first phosphor film **106**.

Alternatively, other suitable technique may be used to coat the LED emitters **104**. In another embodiment, the first phosphor material is applied to the LED emitters **104** by screen print. The first mask **108** is used as a screen printing plate. Additionally, a squeegee blade or a roller may be used to move the first phosphor material to the LED emitters **104** through the openings **110**.

Referring to FIGS. **7** and **8**, the method **150** proceeds to step **160** by dispensing a second phosphor material to the LED emitters **104**, forming a second phosphor film **116** on the first phosphor film **106**. In the present embodiment, the second phosphor film **116** is formed by spray using a second mask **118**.

The second mask **118** includes a suitable mask substrate, such as a metal substrate, a ceramic substrate, or a quartz substrate. The second mask **118** also includes various openings **120** formed in the mask substrate. The mask **118** are positioned over the substrate **102** such that the apertures **120** of the mask **118** are aligned with respective LED emitters **104**. The dimensions of mask **118** (aperture widths, aperture locations, and the like) are designed and tuned to define the second phosphor film **116** and the geometry and/or shape of the second phosphor film **116**. In one example, the mask **118** is positioned a distance above the substrate **102** without direct contact with the first phosphor film **106**.

The plurality of openings **120** of the second mask **118** are designed to have a proper shape and size such that the second phosphor film **116** is disposed on the first phosphor film **106** and partially covers the first phosphor film **106**.

In one example, the openings **120** are designed to be square openings. Each of the openings **120** in the second mask **118** includes a dimension **D2** as illustrated in FIG. **7**. When the openings **120** are square openings, the dimension **D2** is the width of the respective square opening. In the present embodiment, the openings **120** are designed to the same dimension **D2**.

The openings **120** of the second mask **118** are designed differently from those of the first mask **108**. Particularly, the dimension **D2** of the openings **120** is less than the dimension **D1** of the openings **110**.

The second phosphor material is applied to the LED emitters **104** through the openings **120** of the second mask **118** by spray. A spray module **122**, is provided for spray coating the LED emitters **104**. The spray module **122** is coupled with a supply module to provide the second phosphor material for spray coating **124**. Alternatively, other technology, such as screen print, may be used to form the second phosphor film **116**.

Accordingly, thus formed second phosphor film **116** has a smaller dimension than that of the first phosphor film **106**. In one example, the dimension of the second phosphor film **116** substantially equals to the dimension **D2** of the openings **120** in the second mask **118**.

Similarly, the second phosphor material is a composite material having a phosphor powder dispersed in a carrying material, such as silicone or epoxy. In one example, the composite phosphor material is a gel-like material that is able to be sprayed to the coating surface. After the second phosphor material is applied to the LED emitters **104**, a high tempera-

ture process may be further applied to cure the coated second phosphor material, forming the second phosphor film **116** on the first phosphor film **106**.

In another embodiment, the first and second phosphor materials are same. For example, both the first and second phosphor materials are designed to emit red light (or yellow light) under the excitation. In another embodiment, the first phosphor material is designed to emit yellow light under the excitation while the second phosphor material is designed to emit red light under the excitation.

FIG. 9 illustrates a sectional view of a semiconductor structure **180** at a fabrication stage constructed according to aspects of the present disclosure in another embodiment. The semiconductor structure **180** includes a plurality of light emitting apparatus, such as the light emitting apparatus **60** in FIG. 2. With reference to FIG. 9, the semiconductor structure **180** and the corresponding method are collectively described.

A plurality of light emitting devices **104** are attached to a substrate **102** similar to the step **152** of the method **150**. One example of the light emitting devices **104** is the light emitting device **52**. In the present embodiment, the light emitting devices **104** are LED chips (or LED emitters). In another embodiment, the substrate **102** includes a semiconductor substrate, such as a silicon wafer. Alternatively, the substrate **102** may include other suitable substrate, such as a metal substrate, a quartz substrate, or a ceramic substrate. In another embodiment, the LED chips are bonded to the substrate **102** with a suitable bonding mechanism, such as eutectic bonding or diffusion bonding. In the present embodiment, various fabrication steps are implemented in a wafer level, resulting in a plurality of light emitting apparatuses.

A phosphor feature **182** is formed on the LED emitters **104** having a first phosphor material. The phosphor feature **182** is disposed and patterned to have a non-flat surface profile such that the emitted light has a less dependence over the emitting angle, enhancing the emitting light quality and reducing the relative change of the correlated color temperature (CCT) thereof.

In one embodiment, the phosphor material is a composite material having a phosphor dispersed in a carrying material, such as silicone or epoxy. The phosphor emits red or yellow light under excitation according to one example.

In the present embodiment, the phosphor feature **182** is formed by spray using a mask **184**. The mask includes a mask substrate of a material, such as metal, quartz or ceramic material, with the openings **186** formed in the mask substrate. The mask **182** are positioned over the substrate **102** such that the apertures **186** of the mask **184** are aligned with respective LED emitters **104**. Particularly, the openings **186** includes subsets of openings, such as a subset of openings **186a**. Each subset of openings is aligned with one LED emitter.

The openings **186** are designed and tuned to define the phosphor features **182** and the geometry and/or shape thereof. The plurality of openings **186** of the mask **184** may be designed to have a proper shape, such as disk, square, or rectangle.

The phosphor material is applied to the LED emitters **104** through the openings **186** of the mask **184** by spray. A spray mechanism, such as a spray module (or a spray head) **188**, is provided for spray coating the LED emitters **104**. The spray module **188** is coupled with a supply module to provide the phosphor material for spray coating **190**.

Furthermore, the geometry of the phosphor feature **182** is related to the design of the openings **186** in the mask **184**. Each phosphor feature **182** includes a plurality of sub-features corresponding to the respective subset of the openings **186**. In the depicted example, the each subset of openings **186**

includes 3×3 openings. Accordingly, each phosphor feature **182** includes 3×3 sub-features.

Each of the openings **186** has a size (or width) **D3** substantially smaller than the size of the LED emitter **104**. The size **D3** of the openings **186** is substantially smaller than the size **D1** of the openings mask **110** in FIG. 6 as well.

When the mask **184** is positioned substantially close to the LED emitters **104** and the phosphor material is applied to the LED emitters **104** through the openings **186** by spray coating, the dimension of each sub-feature in the phosphor feature **182** substantially equals to the dimension **D3** of the openings **186** in the mask **184**.

After the phosphor material is applied to the LED emitters **104**, a high temperature process may be further applied to cure the coated first phosphor material, forming the phosphor features **182**. Alternatively, other suitable technique, such as screen printing, may be used to coat the LED emitters **104**. Thus formed phosphor feature **182** is similar to the phosphor feature **62** having an uneven surface profile that includes a plurality of peak points and a plurality of dip points. The dip points are substantially below the peak point in a sectional view. In the present embodiment, each sub-feature of the phosphor feature **182** is defined between two neighbor dip points.

FIG. 10 is a flowchart of a method **200** making a semiconductor structure in one embodiment. FIG. 11 illustrates a sectional view of a semiconductor structure **210** at a fabrication stage constructed according to aspects of the present disclosure in one embodiment. The semiconductor structure **210** includes a plurality of light emitting apparatus, such as the light emitting apparatus **66** in FIG. 4A. Different from the method **150**, the method **200** uses both the first mask **108** and the second mask **118** simultaneously. With references to FIGS. 10 and 11, the semiconductor structure **210** and the method **200** are collectively described.

The method **200** begins at step **202** by attaching to a substrate **102** with a plurality of light emitting devices **104**. The step **202** is similar to the step **152** of FIG. 2. In one example, the light emitting devices **104** is the light emitting device **52**. In the present embodiment, the light emitting devices **104** are LED chips (or LED emitters). In another embodiment, the substrate **102** includes a semiconductor substrate, such as a silicon wafer. Alternatively, the substrate **102** may include other suitable substrate, such as a metal substrate, a quartz substrate, or a ceramic substrate. In another embodiment, the LED chips are bonded to the substrate **102** with a suitable bonding mechanism, such as eutectic bonding or diffusion bonding. In the present embodiment, various fabrication steps are implemented in a wafer level, resulting in a plurality of LED apparatuses.

The method **200** proceeds to step **204** by dispensing a first phosphor material to the LED emitters **104**, forming a first phosphor film **106** on the LED emitters **104**. In the present embodiment, the first phosphor film **106** is formed by spray using a first mask **108** and a second mask **118** simultaneously. Particularly, the first mask **108** and the second mask **118** are stacked such that the first phosphor material is sprayed through the openings **110** of the first mask **108** and the openings **120** of the second mask **118**.

The first mask **108** includes openings **110** formed in the respective mask substrate. Each of the openings **110** in the first mask **108** includes a first dimension **D1**. Similarly, the second mask **118** includes openings **120** formed in the respective mask substrate. Each of the openings **120** in the second mask **118** includes a second dimension **D2**. The second dimension is less than the first dimension **D1**. The second mask **118** is stacked on the first mask **108** such that their



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respective openings are aligned, respectively. In the present embodiment, the first mask **108** and the second mask **118** are configured such that central axis of the respective openings **120** are aligned with the central axis of the respective openings **110**, respectively. The first mask **108** and the second mask **118** thus combined together to provide the combined openings or shaped openings (**110** and **120**) to confine the spray of the first phosphor material.

The combined masks **108** and **118** are positioned over the substrate **102** such that the openings **110** and **120** are aligned with respective LED emitters **104**. Particularly, the central axis of the respective shaped openings (**110** and **120**) are aligned with the central axis of the respective LED emitters **104**. The dimensions of combined masks **108** and **118** (opening widths, opening locations, and the like) are designed and tuned to define the first phosphor film **106** and the geometry and/or shape of the first phosphor film. The emitters **104** have a dimension  $D$ . In a particular embodiment, the second dimension  $D2$  is less than  $D$  and the first dimension  $D1$  is substantially equal to  $D$ .

The second openings **120** confine the sprayed first phosphor material to substantially land on central regions of the top surface of the LED emitters **104**. The first openings **110** confine the angle-sprayed first phosphor material to substantially land on edge regions of the top surface of the LED emitters **104**. Thus formed first phosphor film **106** has a curved profile. The thickness of the first phosphor film **106** in the central regions is greater than the thickness of the first phosphor film **106** in the edge regions.

The first phosphor material is applied to the LED emitters **104** through the combined openings by spray. A spray mechanism, such as a spray module (or a spray head) **212**, is provided for spray coating the LED emitters **104**. The spray module **212** is coupled with a supply module to provide the first phosphor material for spray coating **214**.

In the present embodiment, the first phosphor material is a composite material having a phosphor powder dispersed in a carrying material, such as silicone or epoxy. After the first phosphor material is applied to the LED emitters **104**, a high temperature process may be further applied to cure the coated first phosphor material, forming the first phosphor film **106**.

Alternatively, a second phosphor material may be coated on the first phosphor film **106** by another spray step. In one embodiment, the first phosphor material is designed to emit yellow light under the excitation while the second phosphor material is designed to emit red light under the excitation.

Although various features and steps are described according to various aspects in one or more embodiments, other alternatives may present without departure from the scope of the present disclosure. For example, the semiconductor substrate **100** is further diced to form various LED apparatuses. Thus, the present disclosure provides a wafer level packaging with reduced manufacturing cost and an LED apparatus each having a phosphor feature that has a first phosphor film and a second phosphor film. The second phosphor film is patterned to have a smaller dimension than the first phosphor film. Thus, the disclosed method provides a wafer level packaging with reduced manufacturing cost and improved product quality.

The various aspects of this disclosure are provided to enable one of ordinary skill in the art to practice the present disclosure. Various modifications to aspects presented throughout this disclosure will be readily apparent to those skilled in the art, and the concepts disclosed herein may be extended to other applications. Thus, the claims are not intended to be limited to the various aspects of this disclosure, but are to be accorded the full scope consistent with the language of the claims. All structural and functional equiva-

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lents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims.

In one embodiment, the phosphor feature may include more than two phosphor films. For example, the phosphor feature includes three phosphor films of same or different phosphor materials. Three phosphor films have different sizes to compensate the CCD angle effect.

In another embodiment, the phosphor feature includes two or more phosphor films. At least one of the phosphor films is patterned to have a plurality sub-features to tune the surface profile and reduce the reflection and enhance the light extraction.

Thus, the present disclosure provides one embodiment of a light emitting diode (LED) apparatus. The LED apparatus includes an LED emitter having a top surface; and a phosphor feature disposed on the LED emitter. The phosphor feature includes a first phosphor film disposed on the top surface of the LED emitter and having a first dimension defined in a direction parallel to the top surface of the LED emitter; a second phosphor film disposed on the first phosphor film and having a second dimension defined in the direction; and the second dimension is substantially less than the first dimension.

In one example of the LED apparatus, the first phosphor film includes a first phosphor material; and the second phosphor film includes a second phosphor material different from the first phosphor material.

In furtherance of the example, the first phosphor material emits a first light having a first peak wavelength; and the second phosphor material emits a second light having a second peak wavelength that is substantially greater than the first peak wavelength. In a particular example, the LED emitter emits a blue light; the first phosphor material emits a yellow light upon being excited by the blue light from the LED emitter; and the second phosphor material emits a red light upon being excited by the blue light from the LED emitter.

In another example, the LED emitter includes a first region and a second region surrounding the first region on the top surface; the first phosphor film is disposed in both the first region and the second region; and the second phosphor film is disposed within the first region.

In another example, the first phosphor film and the second phosphor film include a same phosphor material.

In yet another example, the first phosphor film has a first thickness and the second phosphor film has a second thickness; and the phosphor feature has a third thickness in the first region and a fourth thickness in the second region. The third thickness is equal to the sum of the first thickness and the second thickness film; and the fourth thickness is equal to the first thickness.

In another example, at least one of the first and second phosphor films is patterned to have a plurality of sub-features configured in an array.

In another example, the plurality of sub-features each include a shape selected from the group consisting of a disk, a square, and a polygon, in a top view. In yet another example, the plurality of sub-features includes a plurality peak points and a plurality of dip points; and the peak points are interdigitated with the dip points in the direction. In yet another example, the peak points and the dip points are configured periodically along the direction.

The present disclosure also provides another embodiment of a light emitting diode (LED) apparatus. The apparatus

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includes an LED emitter; and a first phosphor layer disposed on the LED emitter and patterned to have a plurality of sub-features in an array.

In one example, the plurality of sub-features each include one shape selected from the group consisting of a disk, a square, and a polygon, in a top view.

In another example, the first phosphor layer has a periodic surface profile that includes a plurality of peak points and a plurality of dip points, the dip points being substantially below the peak points in a sectional view.

In another example, the LED apparatus further includes a second phosphor layer disposed on the first phosphor layer. In furtherance of the example, the first phosphor layer spans to a first dimension in a first direction parallel with a top surface of the LED emitter; the second phosphor layer spans to a second dimension in the first direction; and the first dimension is substantially greater than the second dimension.

In another example, the first phosphor layer includes an encapsulation material containing one of silicone and epoxy; and a phosphor power dispersed in the encapsulation material.

The present disclosure also provides a method of making a light emitting diode (LED) apparatus. The method includes providing a plurality of LED emitters disposed on a substrate; providing a first mask over the plurality of LED emitters, wherein the first mask includes a plurality of first openings; and coating the plurality of LED emitters with phosphor through the first openings of the mask, resulting in each of the LED emitters with a first phosphor feature having a plurality of sub-features.

In one example, the coating the plurality of LED emitters with phosphor includes spraying a phosphor material to the plurality of LED emitters through the first openings of the first mask.

In another example, the coating the plurality of LED emitters with phosphor includes coating the plurality of LED emitters with a phosphor gel using the first mask as a screen printing plate, the phosphor gel including an encapsulation material dispersed with the phosphor.

In yet another example, the providing a first mask includes providing a first mask with the plurality of first openings that has a subset of openings designed to form the plurality of sub-features of the first phosphor feature to one of the LED emitters.

In yet another example, the method further includes providing a second mask over the plurality of LED emitters, wherein the second mask includes a plurality of second openings different from the first openings; and coating the plurality of LED emitters with phosphor through the second openings of the second mask, resulting in each of the LED emitters with a second phosphor feature on the first phosphor feature.

In yet another example, the first openings have a first dimension; the second openings have a second dimension; and the second dimension is less than the first dimension.

In yet another example, the mask includes a mask substrate of a material selected from the group consisting of metal, quartz and ceramic; and the plurality of first openings are formed in the mask substrate.

The present disclosure also provides another embodiment of a method of making a light emitting diode (LED) apparatus. The method includes providing a plurality of LED emitters disposed on a substrate; providing a first mask over the plurality of LED emitters, wherein the first mask includes a plurality of first openings with a first dimension; coating the plurality of LED emitters using a first phosphor material through the first openings of the first mask; providing a second mask over the plurality of LED emitters, wherein the

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second mask includes a plurality of second openings with a second dimension less than the first dimension; coating the plurality of LED emitters using a second phosphor material through the second openings of the second mask, resulting in each of the LED emitters having a phosphor film and a second phosphor film on the first phosphor film.

The foregoing has outlined features of several embodiments so that those skilled in the art may better understand the detailed description that follows. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions and alterations herein without departing from the spirit and scope of the present disclosure.

What is claimed is:

1. A light-emitting apparatus, comprising:

a package substrate;  
a light-emitting diode (LED) die disposed over the package substrate;  
a first phosphor material disposed on a surface of the LED die, wherein a sidewall of the LED has no first phosphor material disposed thereon; and  
a second phosphor material disposed directly on the first phosphor material;  
wherein the second phosphor material contains a plurality of sub-features that are each shaped in a top view as a disk, a square, or a polygon.

2. A light-emitting apparatus, comprising:

a package substrate;  
a light-emitting diode (LED) die disposed over the package substrate;  
a first phosphor material disposed on a surface of the LED die, wherein a sidewall of the LED has no first phosphor material disposed thereon; and  
a second phosphor material disposed directly on the first phosphor material;  
wherein the second phosphor material contains a plurality of peaks and dips in a cross-sectional view.

3. A light-emitting apparatus, comprising:

a package substrate;  
a light-emitting diode (LED) die disposed over the package substrate;  
a first phosphor material disposed on a surface of the LED die, wherein a sidewall of the LED has no first phosphor material disposed thereon; and  
a second phosphor material disposed directly on the first phosphor material;  
wherein the second phosphor material is circumferentially surrounded by the first phosphor in a top view.

4. A light-emitting apparatus, comprising:

a light-emitting diode (LED) die;  
a first phosphor material disposed on a surface of the LED die, wherein a sidewall of the LED has no first phosphor material disposed thereon; and  
a second phosphor material disposed directly on the first phosphor material; wherein the first phosphor material has a first lateral dimension; and  
the second phosphor material has a second lateral dimension that is less than the first lateral dimension, wherein the first phosphor material is disposed between the second phosphor material and the LED die.

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5. The light-emitting apparatus of claim 4, wherein at least one of the first phosphor material and the second phosphor material has a non-flat surface profile.

6. The light-emitting apparatus of claim 4, wherein the first phosphor film circumferentially surrounds the second phosphor film in a top view.

7. The light-emitting apparatus of claim 4, wherein the first phosphor film contains a nitridosilicate doped by a rare earth element.

8. The light-emitting apparatus of claim 4, wherein:  
the first phosphor material emits yellow light under excitation; and  
the second phosphor material emits red light under excitation.

9. The light-emitting apparatus of claim 4, further comprising: a package substrate on which the LED die is disposed.

10. A light-emitting apparatus, comprising:  
a package substrate;

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a plurality of light-emitting diode (LED) dies that are spaced apart from one another;

a first phosphor layer disposed on an upper surface, but not on a sidewall, of each of the LED dies: and

a second phosphor layer disposed on the first phosphor layer of each of the LED dies in a manner such that the first phosphor layer is in physical contact with the second phosphor layer, wherein the second phosphor layer has a different material composition than the first phosphor layer, and wherein for each LED die, the second phosphor layer is circumferentially surrounded by the respective first phosphor layer therebelow in a top view.

11. The light-emitting apparatus of claim 10, wherein at least one of the first phosphor layer and the second phosphor layer has a non-flat surface profile.

12. The light-emitting apparatus of claim 10, wherein the first phosphor layer contains a nitridosilicate doped by a rare earth element.

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